O.W.R.C.

Water Management in Ontario

Research Pub. #21

RESEARCH
PUBLICATION
NO. 21

GRAVITY FILTRATION

OF

ALGAL SUSPENSIONS

THE ONTARIO WATER RESOURCES COMMISSION

GRAVITY FILTRATION

OF

ALGAL SUSPENSIONS

By:

R. H. G. Andrews

August, 1968

Division of Research
Publication No. 21

A. J. Harris
Director

Dr. J. A. Vance
Chairman

D. S. Caverly
General Manager

The Ontario Water Resources Commission

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Clogging of sand filters in water treatment plants by algae can drastically reduce the length of filter runs and add materially to costs. Although diatoms are most frequently the cause of filter clogging around the Great Lakes, other species of algae may be troublesome if they appear in large enough numbers.

The purpose of this study was to determine the effectiveness of various filter media in removing algae from water supplies and the extent to which these media clogged. Gravity filtration of two types of algal suspensions was carried out in two model pilot-plant filters located in the OWRC laboratories. Cultures of the green algae *Chlorella*, *Scenedesmus* and *Oocistus* and the flagellate *Euglena* were maintained for filtration.

The program consisted of experimental filter runs through various media including two sizes of sand, anthracite, and combinations of these at flow rates from 2 U.S. gpm/ft^2 to as high as 10 U.S. gpm/ft^2. Concentrations of the algal suspensions were high and varied considerably from run to run.

This report consists of two main sections, the first describing the model filters themselves and their operation, and the second the results of the filter runs.

There is considerable mixing of British and metric units throughout this report (e.g. media depths and flows in British units, media sizes and head losses in metric units). Unfortunately, this is common practice in filtration papers, and has been followed in this case for easier comprehension by the reader.

2 PILOT FILTER APPARATUS AND OPERATION

2.1 Description of Filters

Two filter columns of acrylic tubing were used for the filter experiments. The model filters were about 6 ft high and 6 inches in diameter, with manometer taps inserted 5 inches from the bottom and every 6 inches up the columns, as well as one in the effluent pipe. The filter media were supported by a screen over a single layer of glass balls. The filters were supported on an angle-iron framework. Photographs and a schematic diagram of the filters are presented in Figures 1 and 2.

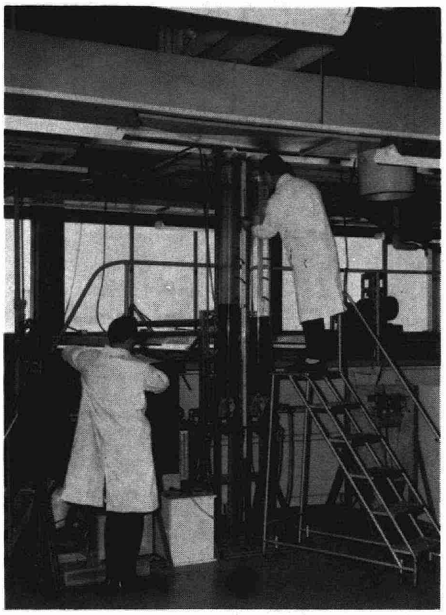
Algal cultures to be filtered were grown in an 8' x 8' x 4' steel tank, and later in a large polyethylene drum placed inside the tank. A bank of Gro-Lux lamps above the tank provided a constant light source to support algal growth.

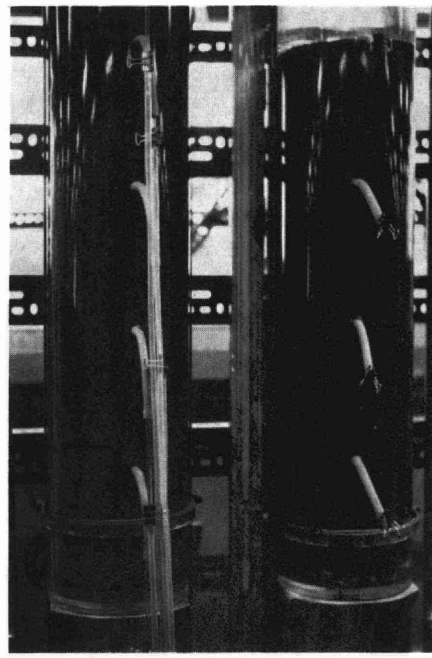
A Sigrist turbidimeter with recorder connected provided continuous measurement of the effluent turbidity. Flow through the filters was controlled by reference to a flowmeter placed between the filters and the turbidimeter. Backwashing of the filters was accomplished by drawing tap water from an overhead line.

2.2 Filter Media

Three materials were used in various combinations to make up six different filter media. Two sizes of sand were used (effective diameters 0.31 mm and 0.55 mm) and anthracite (#1-½ Anthrafilt) of 0.95 mm effective diameter. The sieve analyses of these filter media are shown in Figure 3.

The two sands were compared at depths of 6" and four other media at 27" depths. A mixed-media filter comprised of 6" of 0.31 mm diameter sand overlain by 21" of anthracite was so called because of the wide interface caused by mixing of the sand and anthracite. A combination of 6" of Ottawa sand of larger grain size and 21" of anthracite produced very





A

B

Figure 1: A. Pilot filters with algae tank in background.

B. Close-up of filters showing manometer taps.

Mixed-media filter on left.

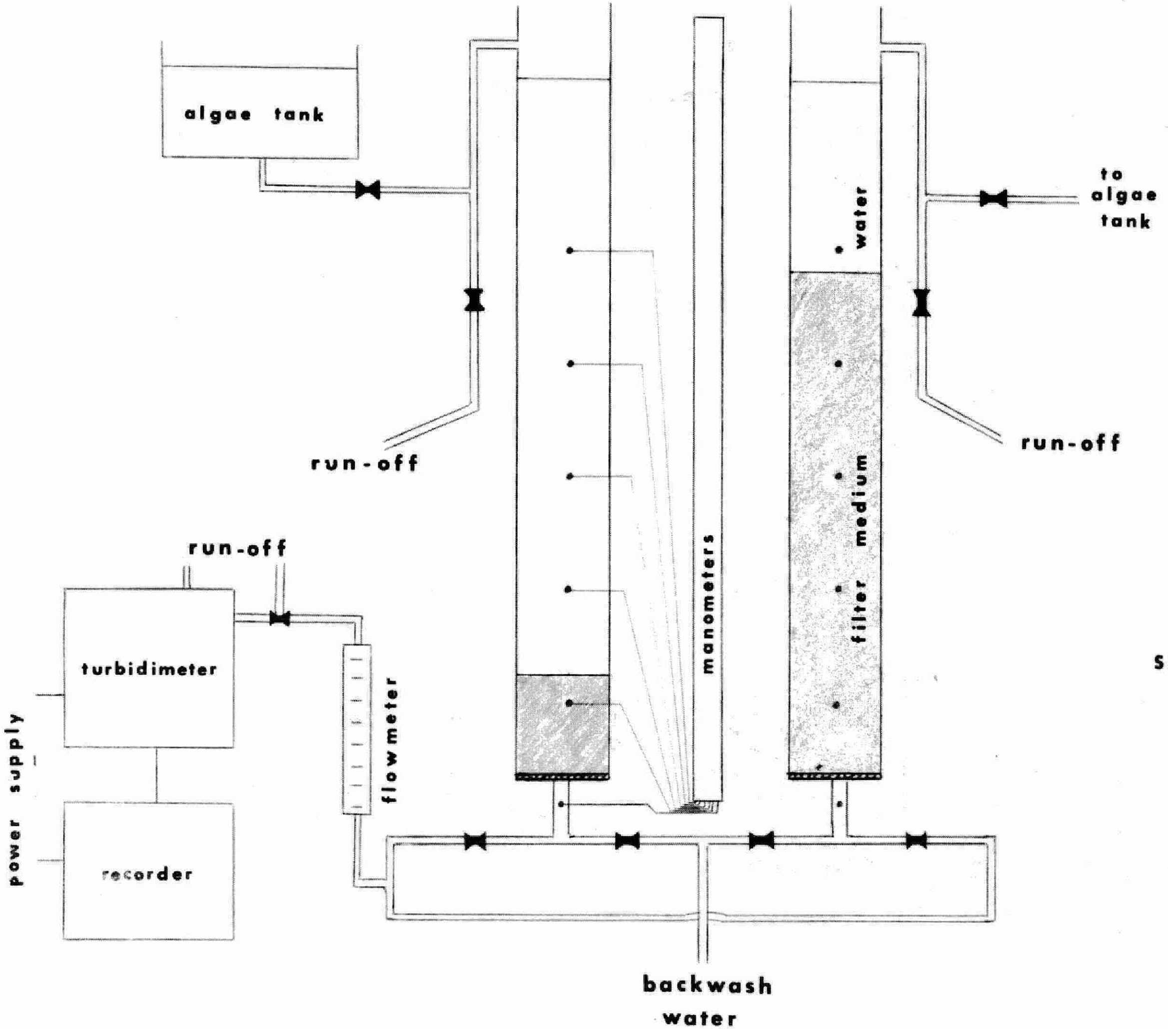


FIGURE 2

SCHEMATIC DIAGRAM
OF
GRAVITY FILTERS

	Effective diameter (mm)	Uniformity Coefficient
Sand	0.31	1.55
Ottawa sand	0.55	1.55
#1 1/2 anthrafilt	0.95	1.76

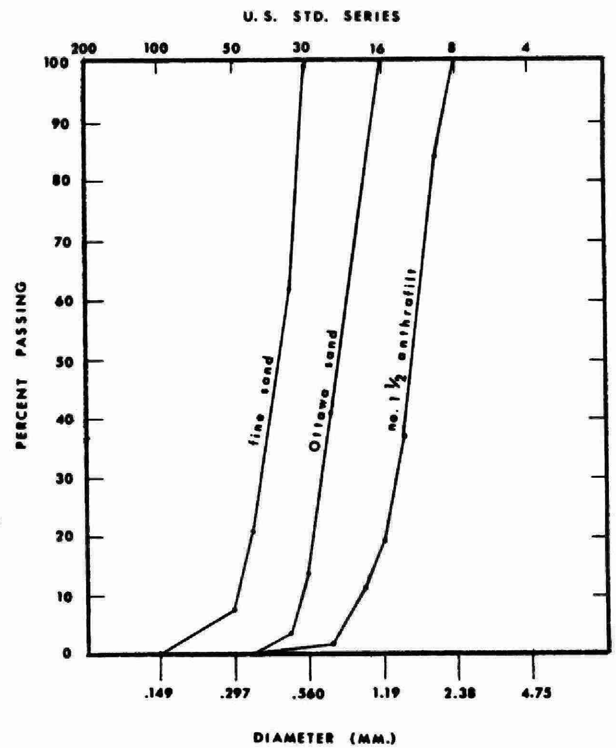


Figure 3

SIEVE ANALYSES

little interfacial mixing upon backwashing, and is referred to as the dual-media filter. In addition, filter runs were made through 27" of fine sand and through anthracite.

2.3 Operation

A total of 78 usable filter runs were obtained with algae suspensions of varying concentration. A summary of the tests performed comprises Table 1. Flow rates of 2, 4 and 6 U.S. gpm/ft^2 were used throughout the program for purposes of comparison, although higher rates were found possible on occasion. The lengths of the experiments ranged from two to seven hours, with most of the *Euglena* runs tending towards the lower figure. No attempt was made to run the filters until clogging prevented passage of the suspensions at the chosen flow rates, although in some cases this occurred very quickly.

Initially, tap water was passed through the empty filter columns to determine the effect on the lowest manometer tap of the constriction imposed by the effluent line. The correction to be applied to the observed head losses for different flows is plotted in Figure 4, and is quite large above 5-6 gpm/ft^2. Tap water was applied to the various filter media used at varying flow rates in order to determine their head loss characteristics, the results of which are given in the following section of this report.

In order to evaluate more than one species of algae, cultures of the flagellate *Euglena* and of the green algae *Chlorella*, *Scenedesmus* and *Oocistus* were prepared. The green algae, predominantly *Chlorella*, grew easily in the steel tank, with artificial lighting and gentle diffused aeration providing mixing and some oxygen supply. Small amounts of fertilizer were added periodically to supply nutrients. The concentration of green algae in the tank varied between about 200,000 and 2 million cells/ml, hence the numbers applied to the filters were far in excess of those that might be expected in normal practice.

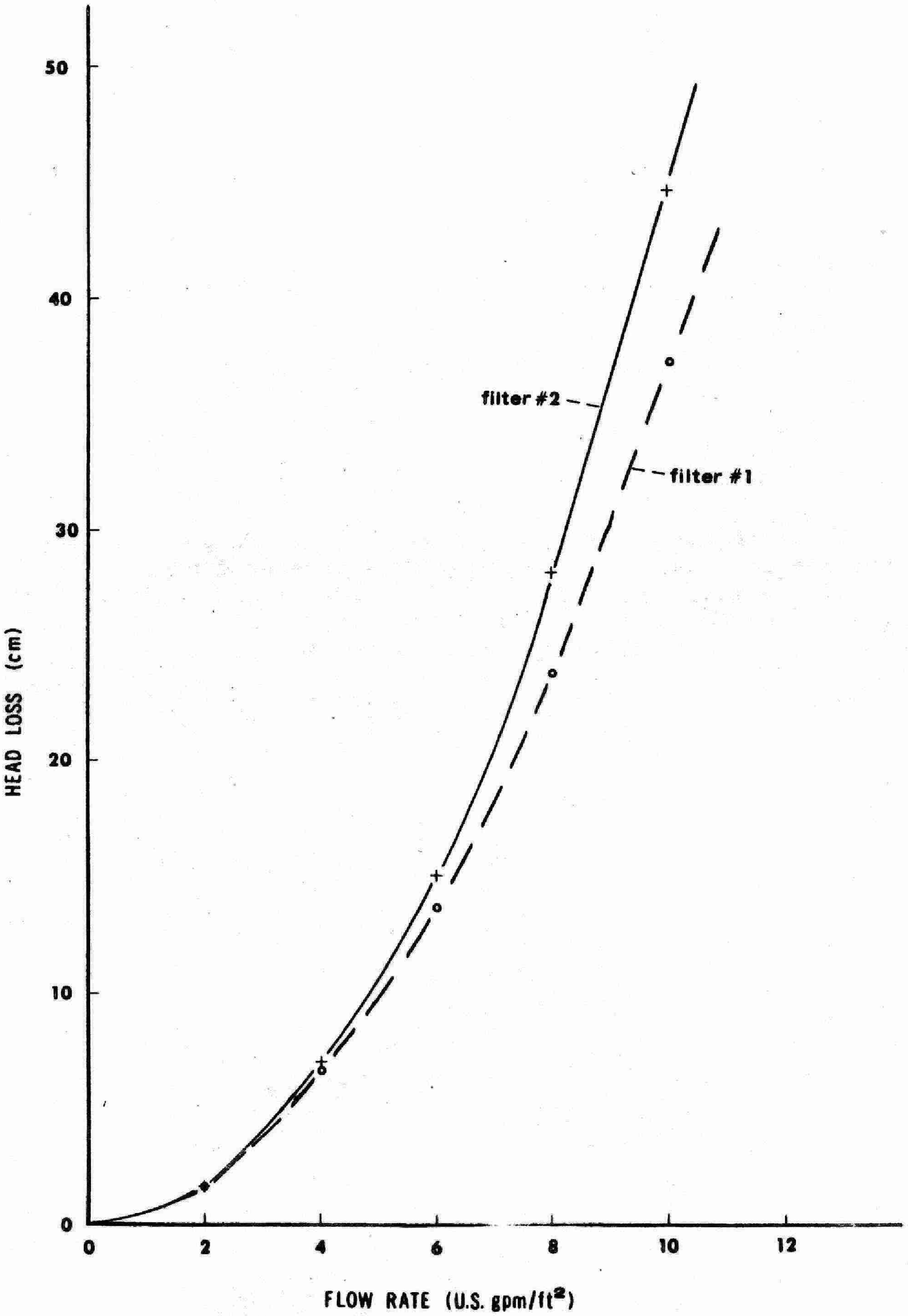
Some difficulty was experienced in maintaining a culture of *Euglena* in the steel tank, so a large polyethylene drum was placed inside the tank. The *Euglena* appeared to

TABLE 1

SUMMARY OF TESTS PERFORMED

	MEDIA	DEPTH	FLOW RATES (gpm/ft^2)	NUMBER OF RUNS Green Algae	NUMBER OF RUNS Euglena
1	sand (0.31 mm)	27"	2,4	6	0
2	sand (0.31 mm)	6"	2,4,6,8	10	7
3	anthracite (0.95 mm)	27"	4,6,8,10	7	6
4	mixed-media (6" sand, 0.31 mm 21" anthracite, 0.95 mm)	27"	2,4,6	15	4
5	Ottawa sand (0.55 mm)	6"	2,4,6	4	6
6	dual-media (6" Ottawa sand, 21" anthracite)	27"	2,4,6	7	6
	TOTALS			49	29

Figure 4: Head Loss vs Flow Rate
(No filter media)



thrive on a periodic diet of split-pea broth. No other nutrients were supplied, and being motile, the *Euglena* required no aeration. The number of *Euglena* cells/ml varied between about 20,000 and 200,000. The culture remained essentially pure until the last filter runs, when *Chlorella* began to appear in increasingly large numbers.

The routine operation of the filters was straightforward. Algae-laden water was pumped from the tank to the top of the filters where a constant head was maintained. The flow rate was controlled by referring to the flowmeter, and once set required little attention unless filter clogging was severe. Spot checks were made of the influent turbidity and grab samples of the influent and effluent were taken for algae counts.

Head losses were recorded at various intervals during the runs, usually after one and two hours, and at the beginning and end. In most cases, at least two runs were secured for each flow rate through a particular medium, and sometimes as many as five runs were made.

The filters were backwashed with tap water for 5-10 minutes after each run. Normally this presented no problem, but the mixed-media and the 27" sand filters sometimes tended to rise up the columns as a single plug, and vigorous rapping on the sides of the columns was required to induce mixing.

3 RESULTS

3.1 Tap Water Runs

For each filter medium which was to be subjected to algae-laden waters, tap water runs were carried out for various flow rates. The head loss characteristics for differing flows are presented in Figure 5, with corrections made for viscosity since the tap water at 11°C was colder than the water in the algae tank (22°C). A linear relationship holds within the range of head losses and flows studied, with the greatest head losses sustained in the 27" sand filter and the smallest in the 27" anthracite filter, as would be expected. Headlosses for the other media ranged between these, with head losses for the mixed-media being about double those of the dual-media filter for corresponding flows.

Composite curves of percentage head loss with depth are drawn in Figure 6 for flows of 2 and 6 U.S. gpm/ft^2. Head losses at 2 gpm/ft^2 through the anthracite filter were too small to be significant, and were not recorded for the 27" sand filter at 6 gpm/ft^2. The sample points correspond to the manometer taps (see Figure 2) where #6 corresponds to the top of the 27" filter, and the distance between points #2 and #3, #3 and #4 etc. is 6".

In comparing the curves at different flows, it may be seen that there is no significant change from 2 to 6 gpm/ft^2. Most of the head loss in the deep sand filter occurs in the upper-most portion, whereas the largest portion of the head losses in the dual and mixed media filters occur in the 6" sand layer at the bottom. Head losses through the anthracite are quite uniform with depth.

3.2 Head Loss Characteristics for Algal Suspensions

3.2.1 Green Algae

The head losses (in cm) and percentage head losses after one hour for the six filter media studied are summarized in Table 2. The numbers 1 - 6 correspond to the media, as outlined in Table 1. The head loss at sample point #1 is

Figure 5: Head Loss vs Flow Rate for Different Media (Tap Water)

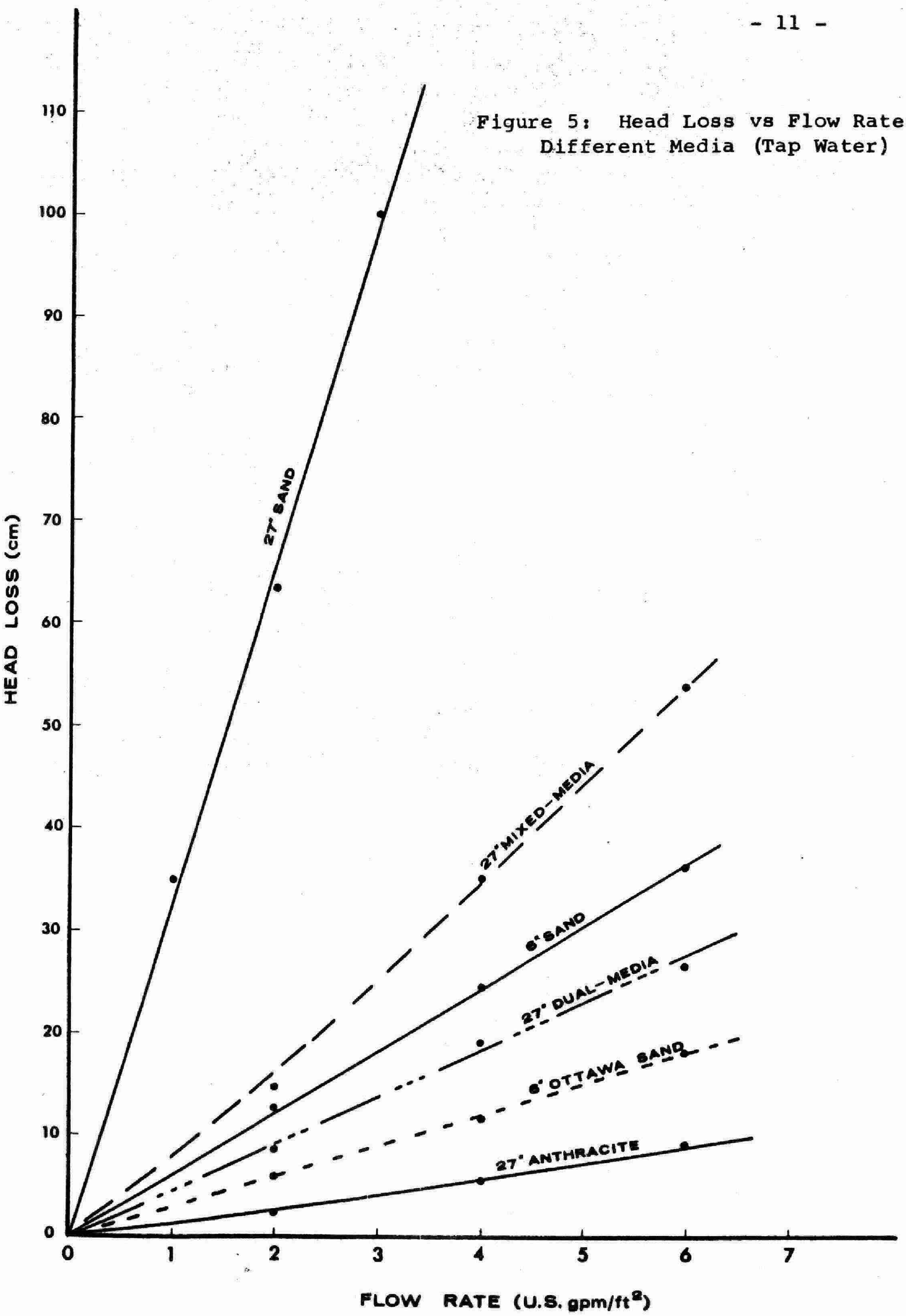


Figure 6A

Composite Curves

Tap Water

$Q = 2$ gpm/ft^2

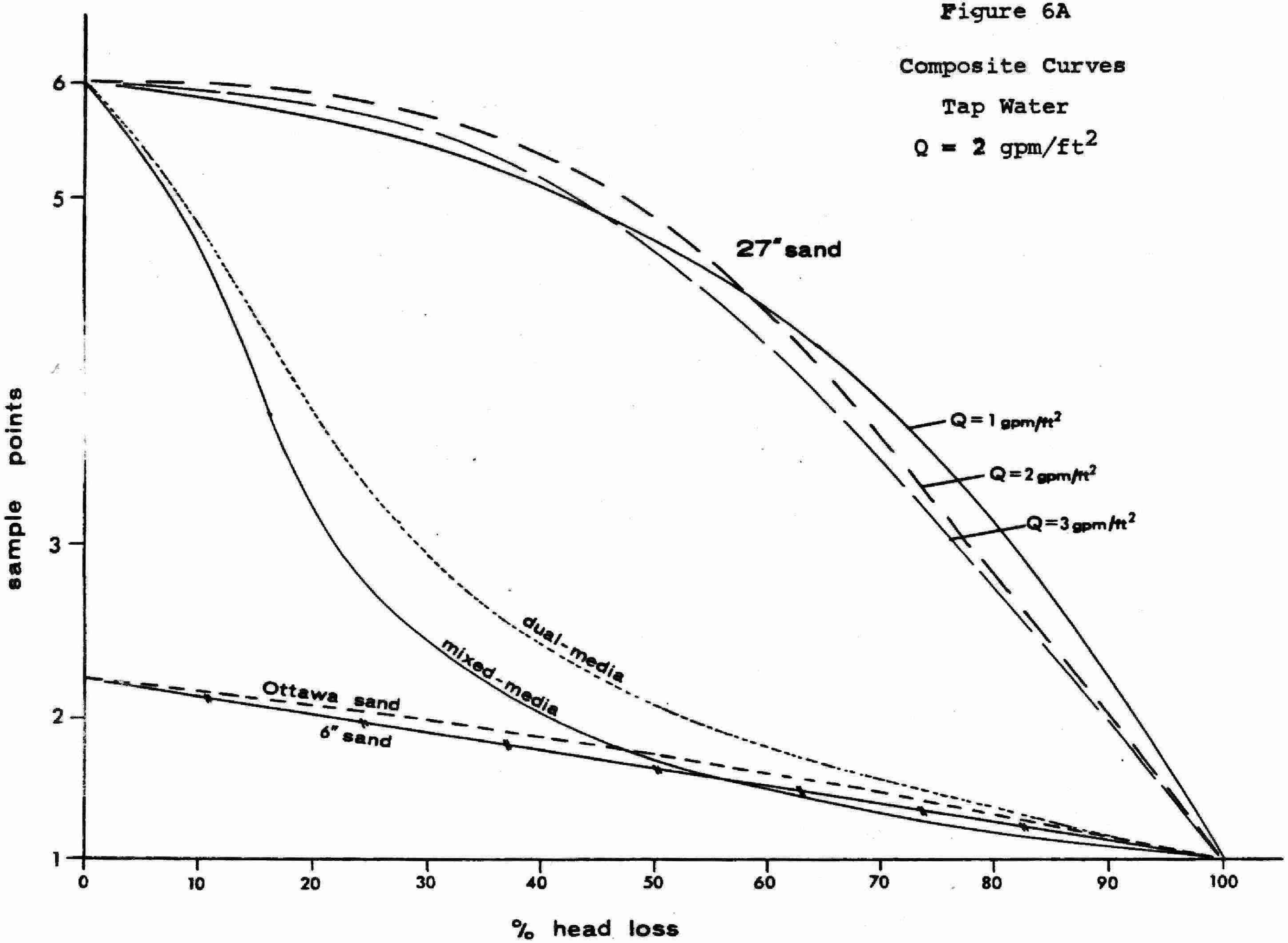
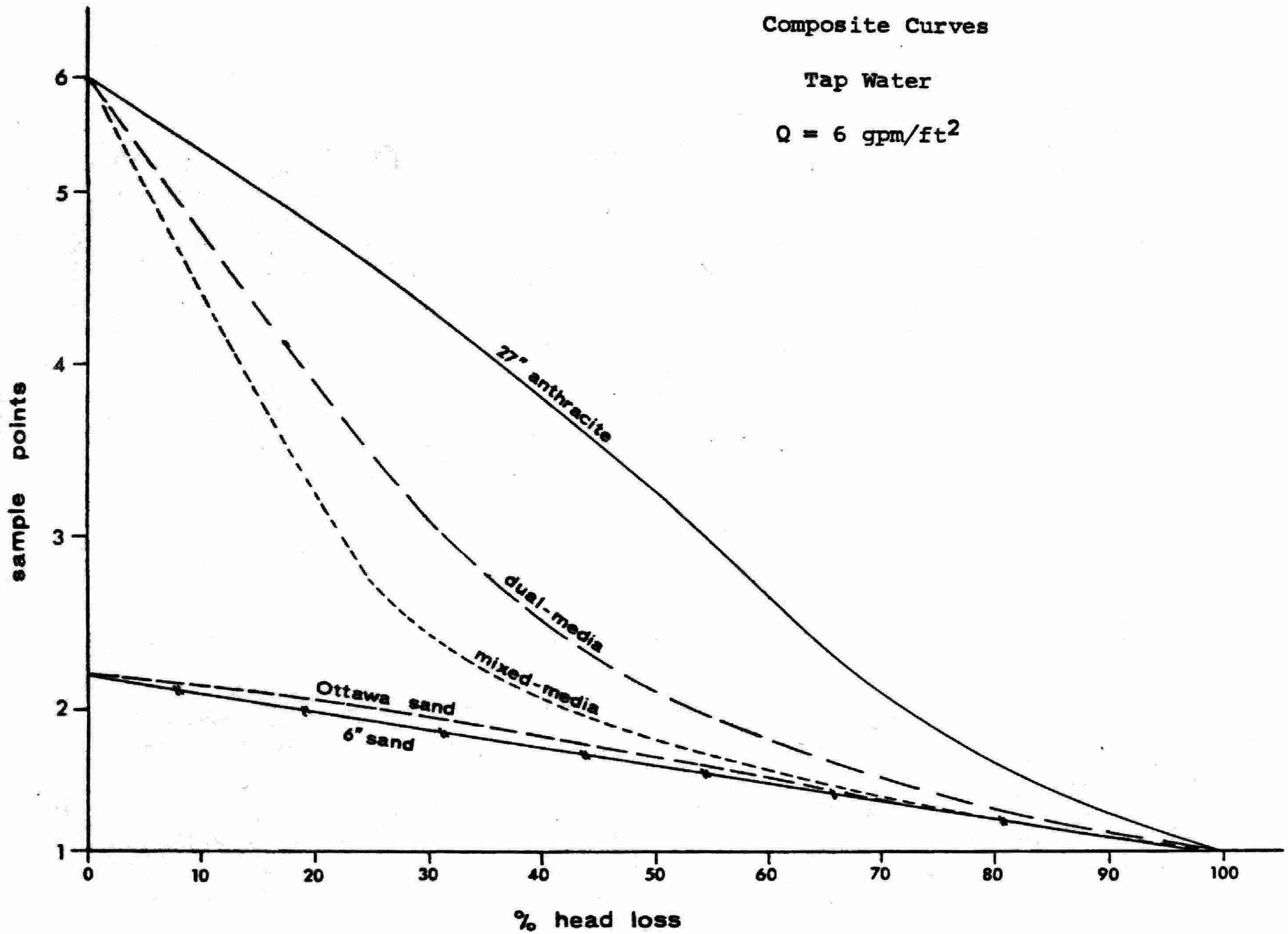


Figure 6B

Composite Curves

Tap Water

$Q = 6\ gpm/ft^2$



<u>TABLE 2</u>

GREEN ALGAE

HEADLOSSES+ AND PERCENTAGE HEADLOSSES – FOR DIFFERENT MEDIA AT FLOW RATES OF 2, 4, 6 gpm/ft^2*

Flow Rate (gpm/ft)	1		2		3		4		5		6	
	H_L	$\%H_L$	H_L	$\%H_L$	H_L	$\%H_L$	H_L	$\%H_L$	H_L	$\%H_L$	H_L	$\%H_L$
	94.5	100	20	100	–	–	18	100	5.5	100	7.5	100
	86	91	5	25			6.5	36	1.5	27	3.5	47
	77.5	81	0	0			4	22	0	0	2	27
2	66.5	69					2.5	13			1	13
	[illegible]	53					1	7			0.5	7
		0					0	0			0	0
	[illegible]	100	37.5	100	6	100	41.5	100	12	100	16.5	100
	10[illegible]	87	8.5	24	6	100	19.5	47	3	25	9.5	58
	84	73	0	0	5	83	10.5	25	0	0	6	36
4	64	56			4	67	6.5	16			4	24
	39	34			2	33	3	8			2	12
	0	0			0	0	0	0			0	0
	–	–	53.5	100	13.5	100	62	100	25	100	30	100
			16.5	30	10.5	80	22	35	5	20	18	59
6			0	0	8	61	13.5	22	0	0	11	37
					6	43	9	14			7	23
					3.5	25	4.5	8			3.5	11
					0	0	0	0			0	0

* Composite at T = 60 minutes.

\+ Head loss in cm

MEDIA:
1. 27" sand
2. 6" sand
3. 27" anthracite
4. 27" mixed-media
5. 6" Ottawa sand
6. 27" dual-media

taken as 100% and the other figures correspond to the sample points up the column. The variation in head loss with depth is shown in Figure 7A.

The most apparent feature of Table 2 and Figure 7A is the high head loss in the 27" sand filter. It was not possible to maintain a flow of 6 gpm/ft^2 through 27" of sand and no runs were attempted with Euglena on this medium. The 6" Ottawa sand filter did not clog as readily as the fine sand filter. The anthracite and dual-media filters were almost identical except for the lowest 6", but the mixed-media bed deviated sharply in the lower portion of the column, reflecting the wide interfacial mixing and the layer of 0.31 mm diameter sand at the bottom.

With reference to Table 2, there is naturally an increase in head loss with flow rate, but no consistent pattern of percentage head loss variation with flow. It is more instructive to look at type curves of particular runs to determine head loss characteristics rather than composite curves. Several type curves are plotted in Figures 8A and 8B. The conclusions drawn from these particular experiments apply in general to the medium under study.

Run #103.2 was at 2 gpm through 27" of fine sand. It is apparent from Figure 8A that most of the algae are retained in the uppermost few inches of the filter, especially after one hour's running time. There is little change with time after one hour.

The main feature of the filtration through the anthracite is the uniformity of retention throughout the length of the bed. After five hours there is some tendency for head loss to increase at the top of the coal filter, but in general the linear trend of percent head loss with depth prevailed with the anthracite medium, with little variation with time.

For the mixed-media filters there was negligible change in percent head loss characteristics with time. From Figure 8B, it may be seen that there is also no consistent change with flow rate. The major increase in head loss occurs in the sand layer at the bottom, although a gradual increase begins in the interfacial mixing zone between sample points #2 and #3.

Run #602.6 through the dual-media filter shows little variation with time. Retention through this filter is more uniform than in the case of the mixed-media bed, and less of the head loss occurs in the (Ottawa) sand layer, the grains being coarser.

3.2.2 Euglena

The head losses and percentage head losses after one hour through the filters when water laden with free-swimming Euglena was applied are listed in Table 3. It was felt that there was not practical value in running tests with the 27" sand filter because of the rapid clogging and resultant high head losses.

Taken by themselves, Table 3 and Figure 7B reveal little about the head loss characteristics with depth that have not been mentioned in the discussion on green algae. But when the head losses in Figures 7A and 7B are compared directly, it may be seen that the Euglena caused higher head losses in every instance, despite the fact that their concentration was an order of magnitude less than that of the Chlorella, Scenedesmus and Oocistus on the average. This was very likely due to the larger dimensions of the Euglena.

As with the suspensions of green algae, there was no consistent variation of head loss characteristics with flow rate. Most of the filter runs with Euglena were over a period of two hours, and little change with time was noted in any of the tests. This is shown in Figure 9A, for example, where there is a slight decrease in percent head loss over the length of the coal bed.

Run #27A6.4 through anthracite demonstrates the near-linear head loss versus depth pattern that was evident with the green algae suspensions. In Figure 9B, the increase in retention through the interfacial zone of the mixed-media bed between sample points #2 and #3 is well marked. Although a similar percent head loss versus depth pattern holds for the dual-media filter in Figure 9C, retention of the Euglena is more uniform through the bed, although most of the retention is again in the Ottawa sand layer.

Figure 7

Composite Headloss vs Depth Curves (Flow = 4 gpm/ft^2)

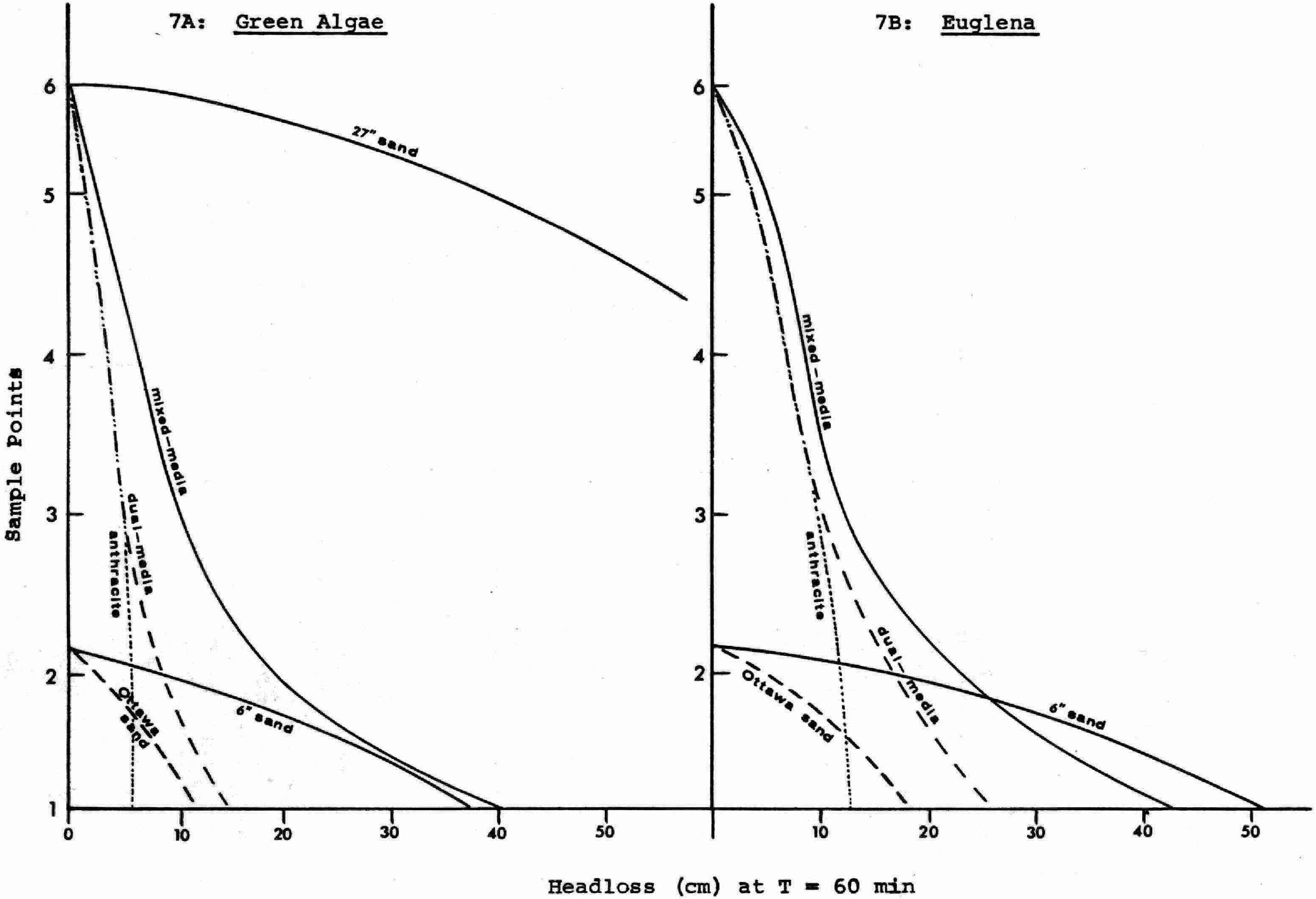


TABLE 3

EUGLENA

HEADLOSSES+ AND PERCENTAGE HEADLOSSES

FOR DIFFERENT MEDIA AT FLOW

RATES OF 2, 4, 6 gpm/ft^{2*}

Flow Rate (gpm/ft^2)	2 H_L	2 $\%H_L$	3 H_L	3 $\%H_L$	4 H_L	4 $\%H_L$	5 H_L	5 $\%H_L$	6 H_L	6 $\%H_L$
2	23	100	7	100	20.5	100	11.5	100	16.5	100
	7	30	6	85	12	59	4	29	8.5	52
	0	0	4.5	67	6.5	32	0	0	5	30
			3	45	4.5	22			3	18
			2	26	2.5	12			1.5	9
			0	0	0	0			0	0
4	50.5	100	13.5	100	43	100	18	100	26.5	100
	17	34	12.5	93	23	54	5	28	17	64
	0	0	10	74	12	28	0	0	10.5	40
			7	52	8.5	20			7	26
			3.5	26	5	12			3.5	13
			0	0	0	0			0	0
6	66	100	24	100	-	-	21	100	39.5	100
	25	38	20.5	85			5	24	24.5	62
	0	0	16.5	69			0	0	16	41
			12	50					10.5	27
			5.5	23					6	15
			0	0					0	0

*Composites at T = 60 min

+Head loss in cm

2. 6" sand
3. 27" anthracite
4. 27" mixed-media
5. 6" Ottawa sand
6. 27" dual-media

Figure 8A

Type Curves

Green Algae

Run 103.2 - 27" Sand

Run 204.8 - 27" Anthracite

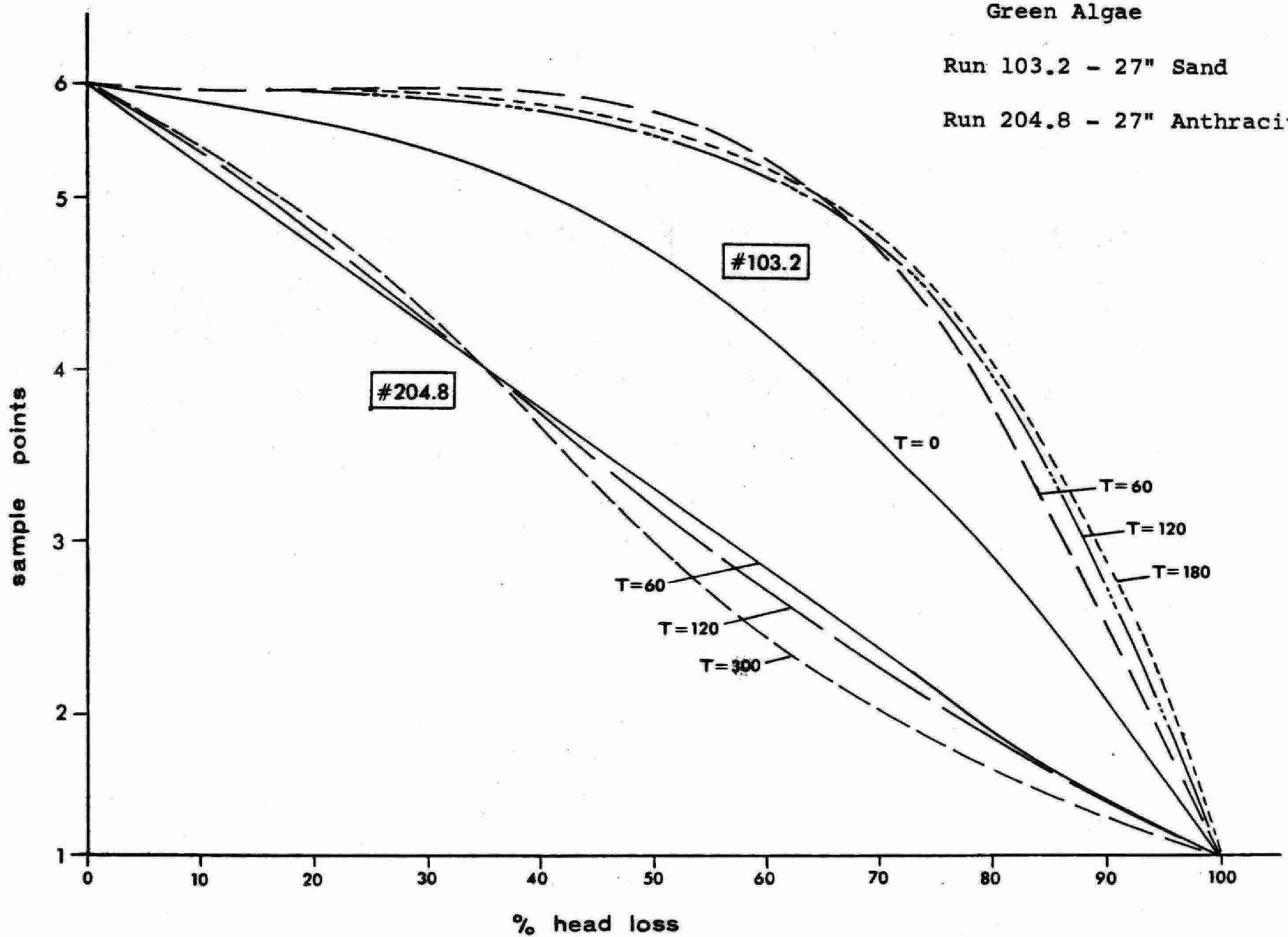


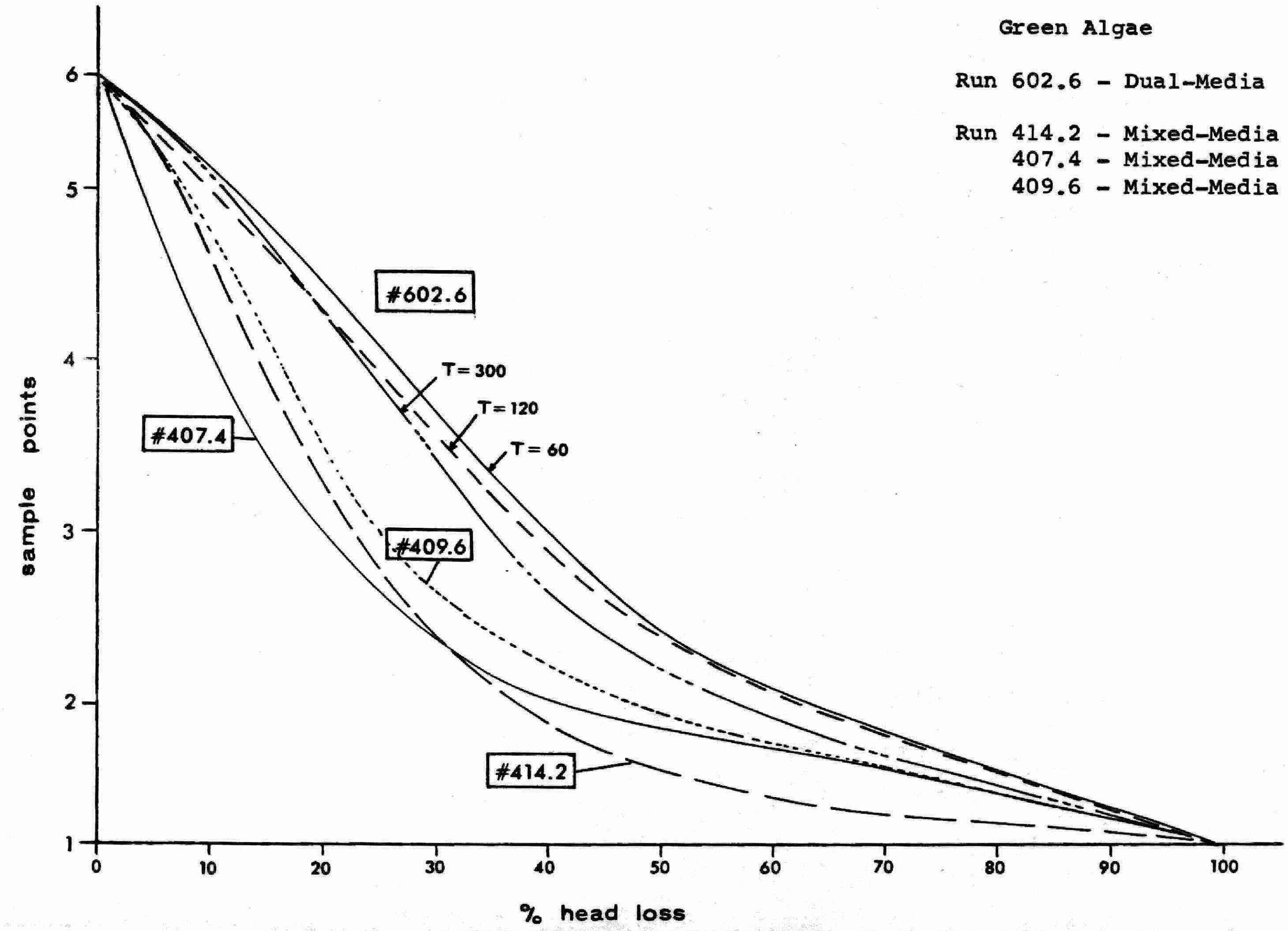
Figure 8B

Type Curves

Green Algae

Run 602.6 - Dual-Media

Run 414.2 - Mixed-Media
407.4 - Mixed-Media
409.6 - Mixed-Media



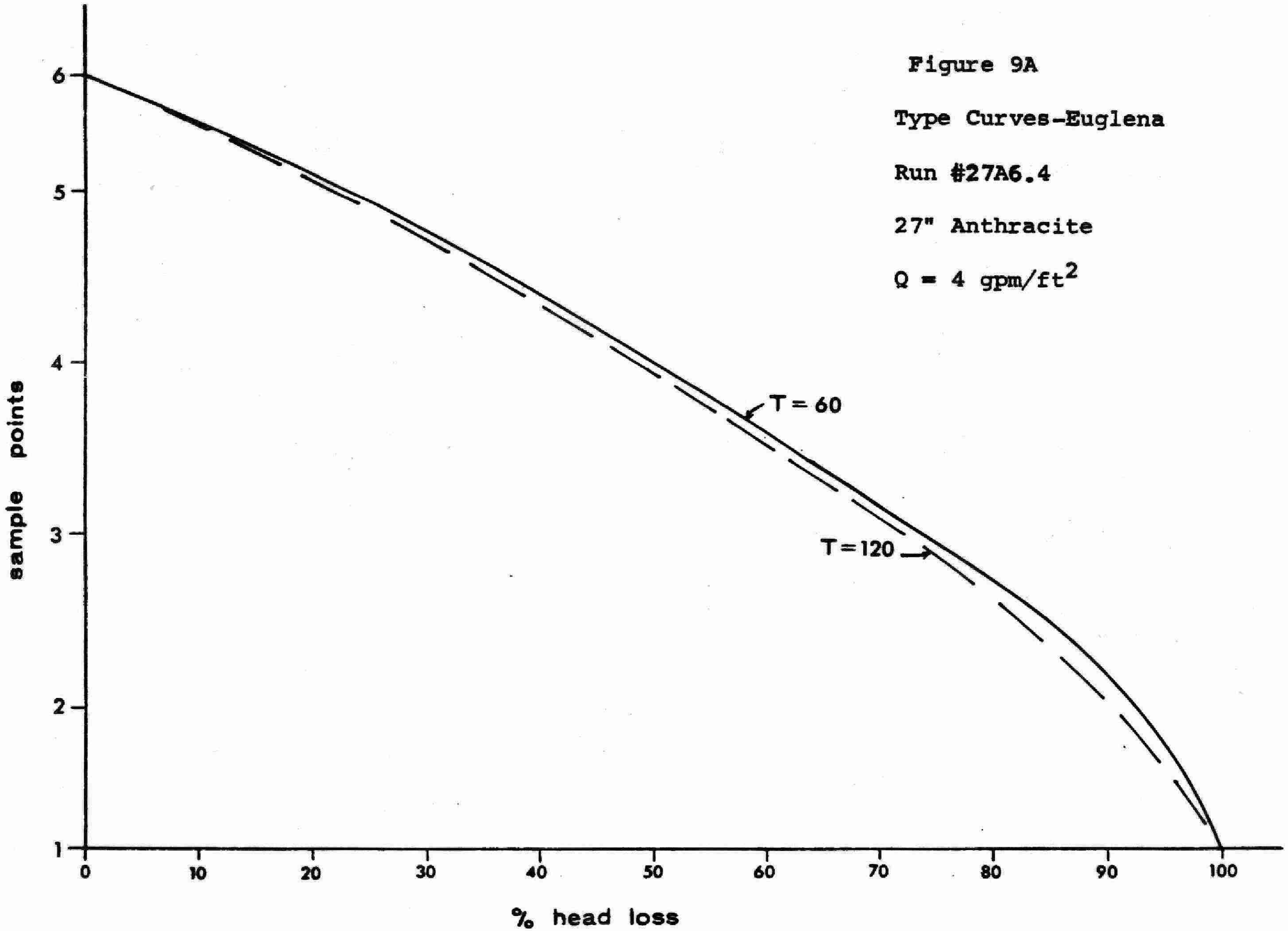


Figure 9A
Type Curves-Euglena
Run #27A6.4
27" Anthracite
Q = 4 gpm/ft2
T = 60
T = 120
sample points
% head loss
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100

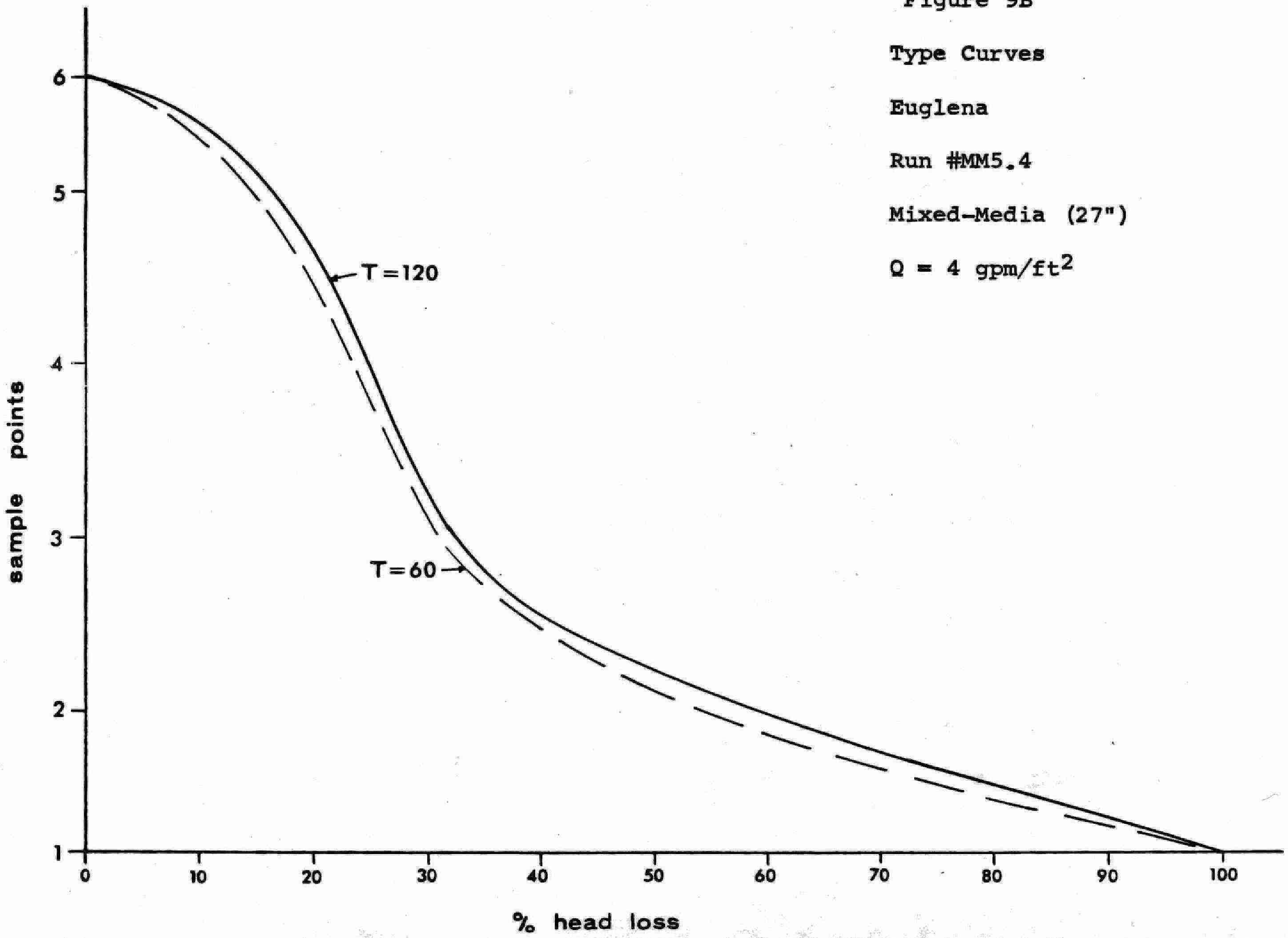


Figure 9B

Type Curves

Euglena

Run #MM5.4

Mixed-Media (27")

Q = 4 gpm/ft^2

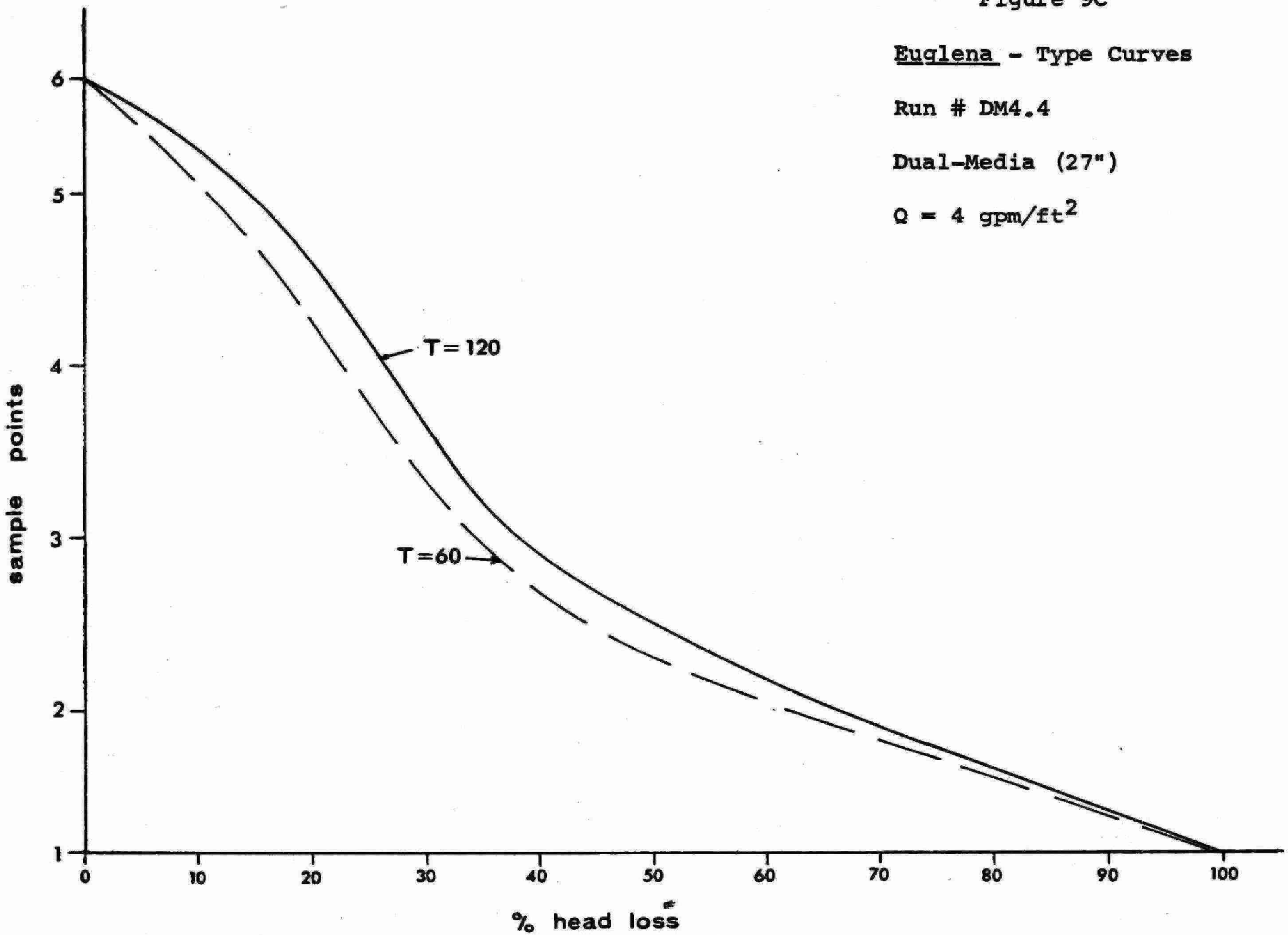
Figure 9C

<u>Euglena</u> - Type Curves

Run # DM4.4

Dual-Media (27")

$Q = 4\ gpm/ft^2$



3.3 Algae and Turbidity Removals

3.3.1 Results

The algae and turbidity measurements are summarized in Table 4. The mean percentage removals are presented for each medium and flow rate. The most significant feature of these results is the ineffectiveness of the filters in removing a large portion of the applied algal loading.

The significance of the turbidity measurements will be discussed briefly in the next section, but it might be pointed out here that in general the turbidities bore little relation to the algal concentration, despite the fact there could be very little particulate matter to contribute towards turbidity.

Although overall averages are of limited meaning where different filter media are involved, 50% of the *Euglena* were removed by the filters and only 18% of the green algae. Direct comparison of the individual media in Table 4 shows that in every case more of the smaller *Chlorella*, *Scenedesmus* and *Oocistus* passed through the filters than the *Euglena*. Only the 27" sand filter retained a significant portion of the green algae, with high head losses.

There was no consistent variation in algal retention with flow rate. There were tendencies for higher removals of *Euglena* at a flow of 2 gpm/ft^2, and of the green algae at 4 gpm/ft^2, but these were neither consistent nor pronounced.

There was no correlation between the applied algal loading and retention of algae in the beds. A statistical analysis of the data presented in the scatter diagrams in Figures 10 and 11 supported this contention.

3.3.2 Significance of Turbidity Measurements

The Sigrist turbidimeter employs a nephelometric principle whereby the light scattered by the sample is compared with the incident light, thus providing colour compensation. For most turbid samples this instrument will produce consistent readings, but the correlations between the numbers of algae cells and the recorded turbidities were poor.

TABLE 4

SUMMARY OF ALGAE AND TURBIDITY REMOVAL DATA

Green Algae

Flow Rate (gpm/ft^2)	A (1)	T (1)	A (2)	T (2)	A (3)	T (3)	A (4)	T (4)	A (5)	T (5)	A (6)	T (6)
2	51	79	19	26	-	-	11	13	(0)	(8)	15	20
4	75	61	(8)	43	5	36	16	20	(0)	(9)	23	26
6	-	-	23	35	5	45	9	41	(12)	(17)	13	9
8	-	-	11	28	16	35	-	-	-	-	-	-
MEAN	58	74	17	33	9	35	11	23	4	11	17	18

Euglena

	A (1)	T (1)	A (2)	T (2)	A (3)	T (3)	A (4)	T (4)	A (5)	T (5)	A (6)	T (6)
2	-	-	60	(10)	69	7	68	-	37	7	72	5
4	-	-	19	9	40	-	76	(8)	47	4	51	5
6	-	-	36	15	48	(4)	-	-	66	3	24	2
MEAN	-	-	38	12	52	-	72	-	50	5	49	4

( ) one reading only

A - % algae reduction

T - % turbidity reduction

1. 27" sand
2. 6" sand
3. 27" anthracite
4. 27" mixed-media
5. 6" Ottawa sand
6. 27" dual-media

Figure 10

GREEN ALGAE -- INFLUENT ALGAE vs PERCENT ALGAE REMOVED

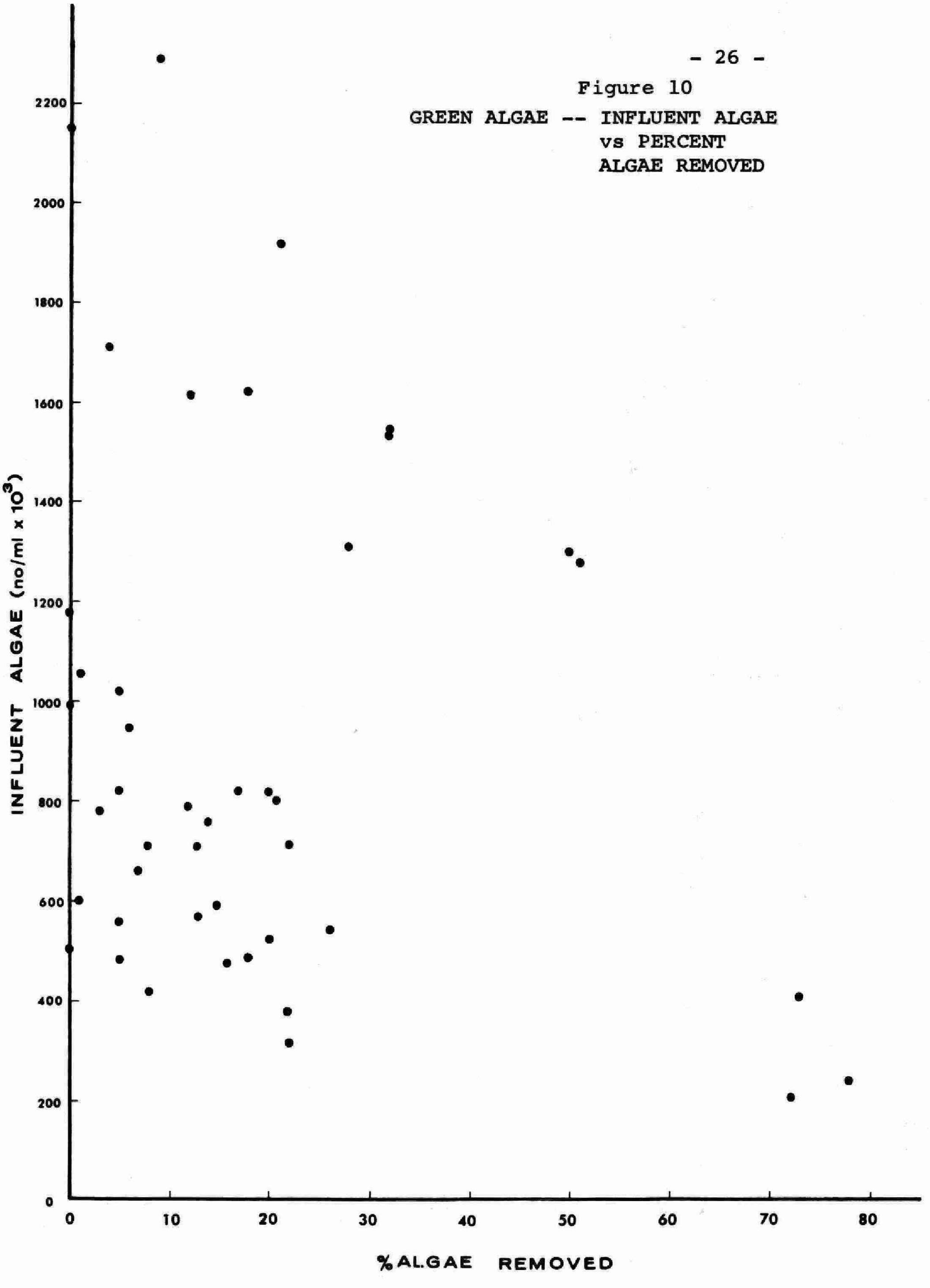
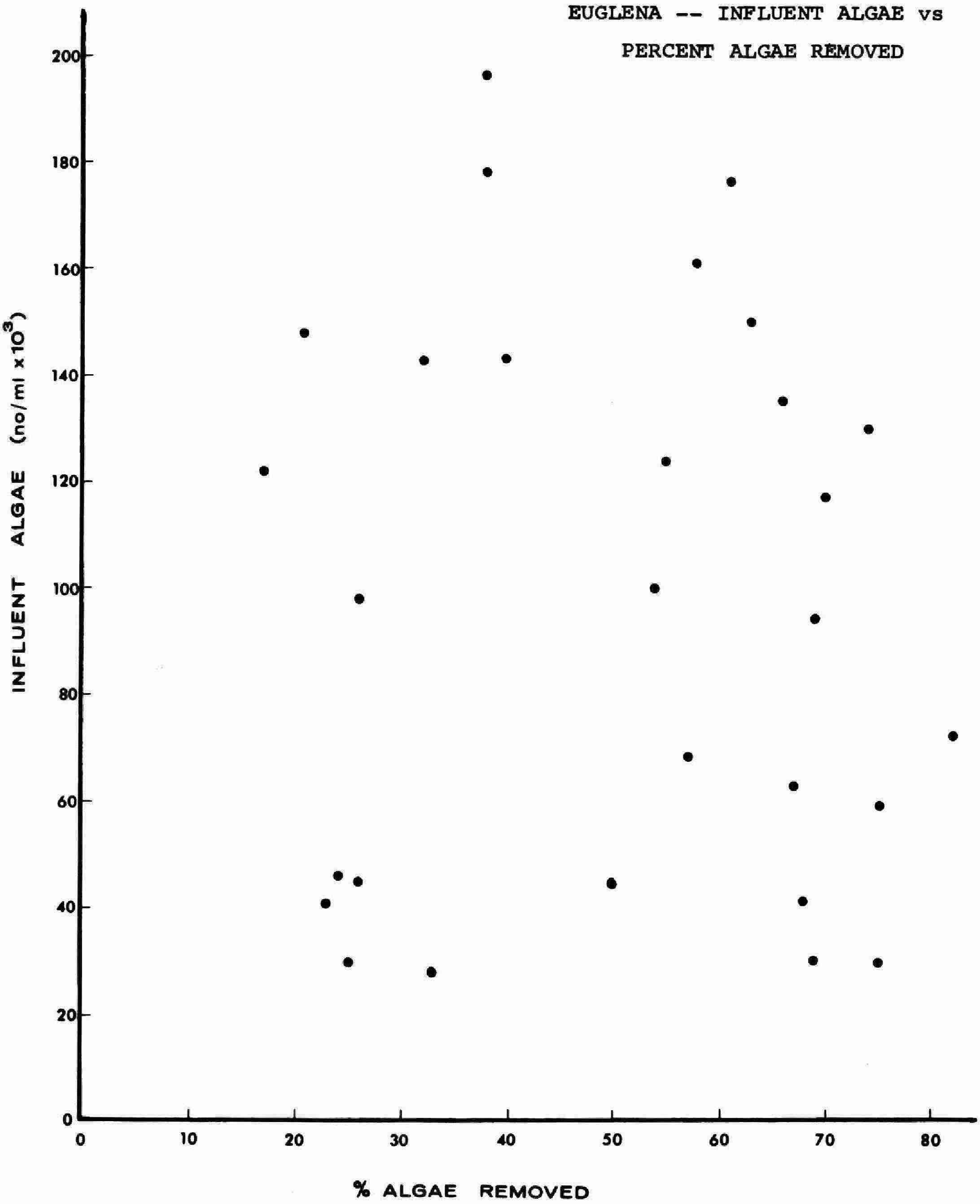


Figure 11

EUGLENA -- INFLUENT ALGAE vs PERCENT ALGAE REMOVED



A statistical analysis of the green algae data revealed that a linear relationship could be postulated (correlation coefficient 0.67) but there was a great deal of scatter in the results (Figure 12). A curvelinear regression analysis produced a very similar result. There appeared to be no relationship at all between the number of Euglena cells and the recorded turbidity. It is evident that a turbidimeter of this type cannot be used as an indication of algal concentration, probably due to the optical properties of the algae.

The turbidities of several samples were determined by the Sigrist and a Hellige turbidimeter, revealing a consistent linear relationship between the two, although the Hellige gave considerably lower readings.

The recorded traces of effluent turbidity were useful for following the salient features of the filter runs, such as the general level of algae clogging and significant "break-throughs". As a rule the turbidity traces were steady over the period of the runs, but several of the Euglena runs employing the 6" sand, 27" anthracite, and mixed-media filters showed sharp irregularities and peaks on the recorded turbidity. This suggested that a series of algae build-ups and break-throughs were occurring. No such patterns were observed when Euglena suspensions were passed through the Ottawa sand and dual-media filters.

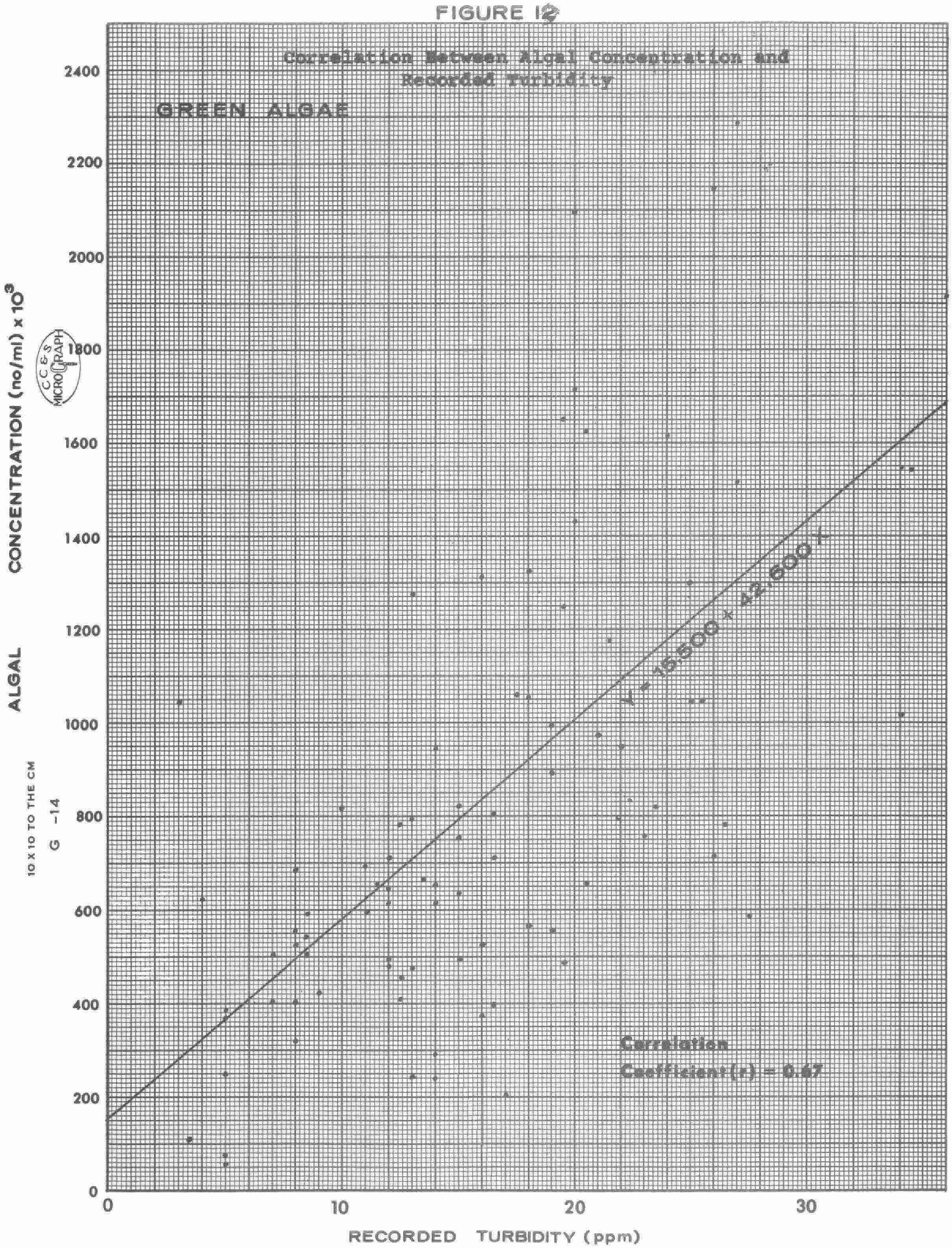
Since the correlation between algae concentration and recorded turbidity was poor, comments on the effects of the applied load to the filters on head losses will be confined to the effects of numbers of algae rather than turbidity.

3.3.3 Effects of Algal Load on Head Loss and Retention

It was brought out in Section 3.2 that there was no significant variation in percentage head loss versus depth characteristics with time. In other words, although the head loss in the filters increased with time, algae were retained at specific depths in the filter bed in the same proportions with time.

Of prime interest in this study were the effects of the applied algal loading on the head losses in the filter.

FIGURE 12


Correlation Between Algal Concentration and Recorded Turbidity
GREEN ALGAE
Y = 15.500 + 42.600X
Correlation Coefficient (r) = 0.67
ALGAL CONCENTRATION (no/ml) x 10^3
RECORDED TURBIDITY (ppm)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
10 X 10 TO THE CM
G -14
C C & S MICROGRAPH

From the data presented in Tables 5 and 6, an attempt was made to see if head losses were associated with higher algae loadings, and when algal concentrations were the same for all runs for a particular flow and media, head losses tended to be the same. There were some exceptions to this trend, mostly in the runs with the green algae.

Some of the typical head loss patterns with time are shown in Figure 13. The numbers beside the curves refer to the influent algae concentration (in no/ml x 10^3). The 27" sand and dual-media filters show a higher head loss with higher algae concentrations. The mixed-media bed at 6 gpm/ft^2 was an exception in that higher head losses were found after two and three hours with only one third of the number of algae.

With data from Table 5, a plot (Figure 14) was made of the head losses after two hours against influent green algae concentration. For most of the filter media there is a slight but consistent increase in head loss with increasing numbers of algae at the flows studied. Head losses were constant or even decreased through the anthracite and mixed-media filters, and only one run was made at each flow rate through the Ottawa sand.

A similar plot of Euglena results from Table 6 is shown in Figure 15. Again the trend is towards higher head losses with higher algae concentrations. Since the range of algal concentrations was small for most flow rates for each media the slopes of some of the lines in Figure 15 can be considered only as estimates.

In an attempt to compare the effects of the Euglena and the green algae on head loss with each other and the tap water head loss characteristics, plots were made of head loss versus flow rate for five filter media. These are composite curves derived from averages of all the runs at a particular flow for each media and algae type (Euglena-E; Green algae - G) and at one (1) and two (2) hours (Figures 16A, 16B, 16C).

In general, the Euglena produced a higher head loss than the smaller Chlorella, Scenedesmus and Oocistus, consistent

TABLE 5

CHANGES IN HEAD LOSS WITH TIME (GREEN ALGAE)

Run	H_L0 (cm)	H_L60 (cm)	H_L120 (cm)	H_LF (cm)	Run Time (hrs)	Algae in (no/mlx10^3)
103.2	70.5	122.5	157.5	172.5	3:0	1274
104.2	60.5	84.5	115	185.5	4:0	1055
105.2	61.5	76.5	95.5	176.5	5:30	411
106.4	120.5	120.5	127	165.5	5:0	242
107.4	-	122.5	145.5	174.5	3:45	206
201.4	5	6	8	12	5:20	2287
212.4	4	5	10	91	7:0	5022
203.6	12.5	13.5	19.5	77	6:0	1018
207.6	9.5	13	14	16.5	3:0	1300
204.8	13	14	15.5	22.5	5:0	757
206.8	12.5	13.5	15.5	16	3:20	820
205.10	14.5	16.5	17.5	20.5	4:30	664
308.2	16.5	20	22	25	3:0	481
309.2	15.5	19.5	22	38.5	5:0	711
310.2	27.5	33.5	42.5	42.5	2:30	1622
302.4	33.5	41	44.5	58	5:0	422
303.6	42.5	54	65.5	97.5	4:0	524
305.6	40.5	49.5	58	63.5	3:0	541
304.8	58.5	71.5	82.5	85.5	4:0	320
306.8	59.5	67.5	79.5	85.5	3:0	505

Run	H_L0 (cm)	H_L60 (cm)	H_L120 (cm)	H_LF (cm)	Run Time (hrs)	Algae in (no/mlx10^3)
401.2	19.5	20	20	21.5	5:0	596
404.2	17	18	18.5	19	3:10	820
408.2	15.5	16	17.5	17	2:40	377
410.2	18	18.5	18.5	19	2:30	804
414.2	17.5	18	19	19	2:30	1713
405.4	35.5	37	39.5	46	5:40	792
406.4	54	58	61	65	4:10	555
407.4	39	41.5	45.5	46.5	2:20	488
412.4	37.5	42	43.5	45.5	2:45	1311
403.6	56	61.5	74	85.5	3:0	711
409.6	70	74.5	76.5	82.5	3:0	567
411.6	58	59.5	72	82.5	4:0	587
413.6	91.5	100.5	107.5	118.5	4:0	780
415.6	60	64.5	67.5	68	2:30	2146
504.2	5	5.5	6	7.5	4:15	994
502.4	10.5	12	12	14.5	6:30	1178
503.6	24.5	25	29	27.5	3:0	1616
601.2	10	14.5	18.5	26	5:0	1916
603.2	7.5	7.5	7.5	9	6:30	711
604.4	15	15	15.5	17.5	4:30	950
606.4	17	18	20.5	21.5	3:0	1542
607.4	16	17	18	18	2:0	1541
602.6	36	34.5	33.5	35	5:0	820
605.6	23.5	25	24.5	26	2:45	478

TABLE 6

CHANGES IN HEAD LOSS WITH TIME (EUGLENA)

Run	$H_L 0$ (cm)	$H_L 60$ (cm)	$H_L 120 = H_L F$ (cm)	Algae in (no/ml$\times 10^3$)
6SE6.2	21.5	25.5	26.5	176
6SE7.2	17.5	20.5	24.5	161
6SE4.4	47.5	54.5	65.5	148
6SE5.4	42.5	46.5	55.5	122
6SE8.6	56.5	64.5	77.5	143
6SE2.6	58.5	70.5	83.5	196
6SE10.6	55.5	63.5	77.5	178
27A1.2	5.5	7	7.5	150
27A2.2	5.5	6.5	9.5	130
27A5.4	-	11	11	100
27A6.4	-	16	18	98.1
27A3.6	-	24	27	143
27A4.6	-	24	26	124
MM1.2	-	23.5	23.5	135
MM2.2	-	17.5	20.5	117
MM3.4	38.5	40.5	44.5	72.2
MM5.4	42.5	45.5	47.5	94.4
60S1.2	11.5	12.5	16.5	44.4
60S2.2	-	10.5	10.5	46.3
60S3.4	18.5	19.5	19.5	62.5
60S4.4	-	16.5	16.5	42.6
60S5.6	-	20.5	21.5	29.6
60S6.6	-	21.5	23.5	68.5
DM1.2	-	17.5	17.5	59.2
DM2.2	15.5	15.5	14.5	40.7
DM3.4	-	27.5	28.5	29.6
DM4.4	-	25.5	25.5	27.8
DM5.6	-	39.5	39.5	40.7
DM6.6	-	39.5	40.5	29.6

Figure 13: Variation of Head Loss with Time for Different Media (Green Algae)

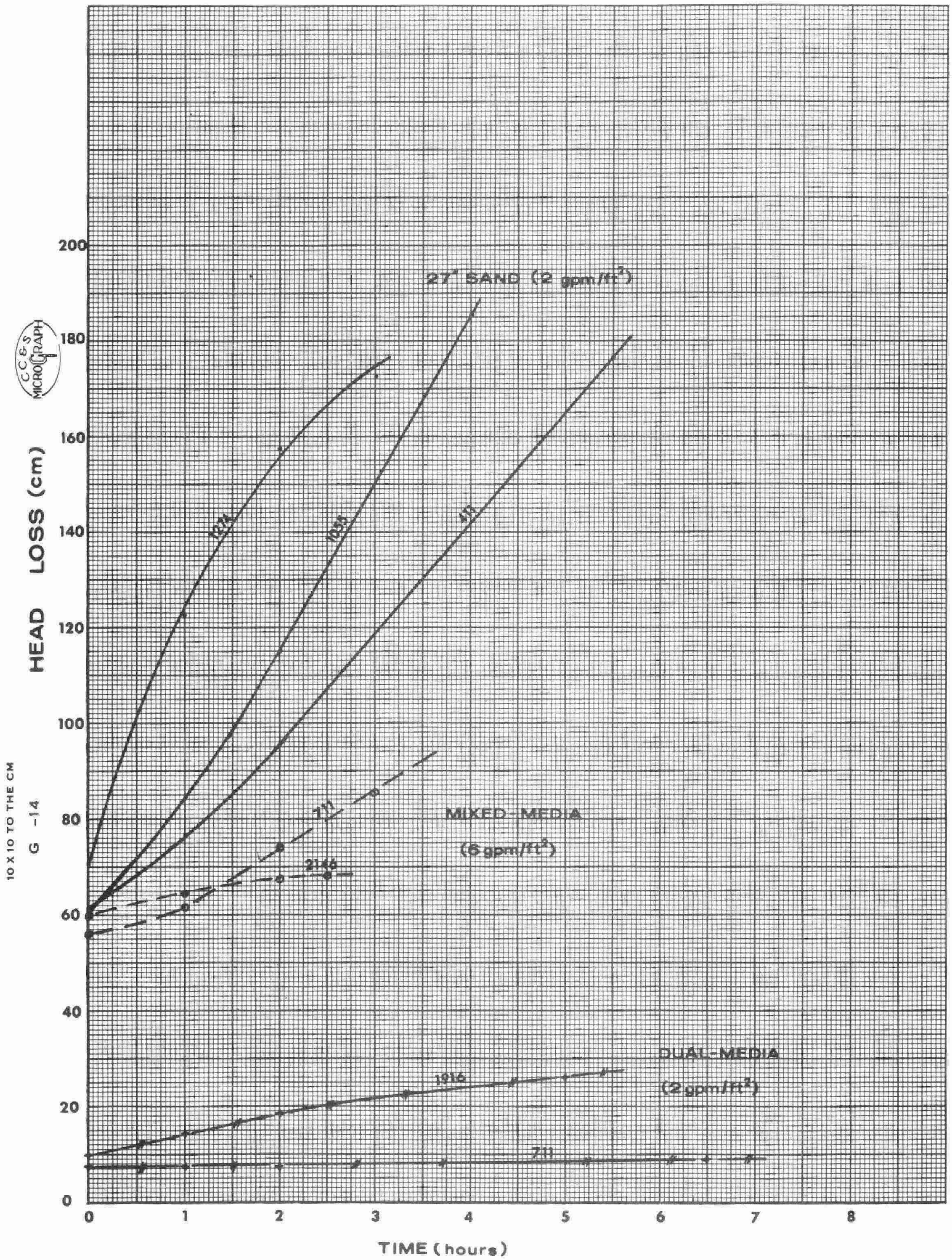


Figure 14: Head loss vs Influent Algae Concentration

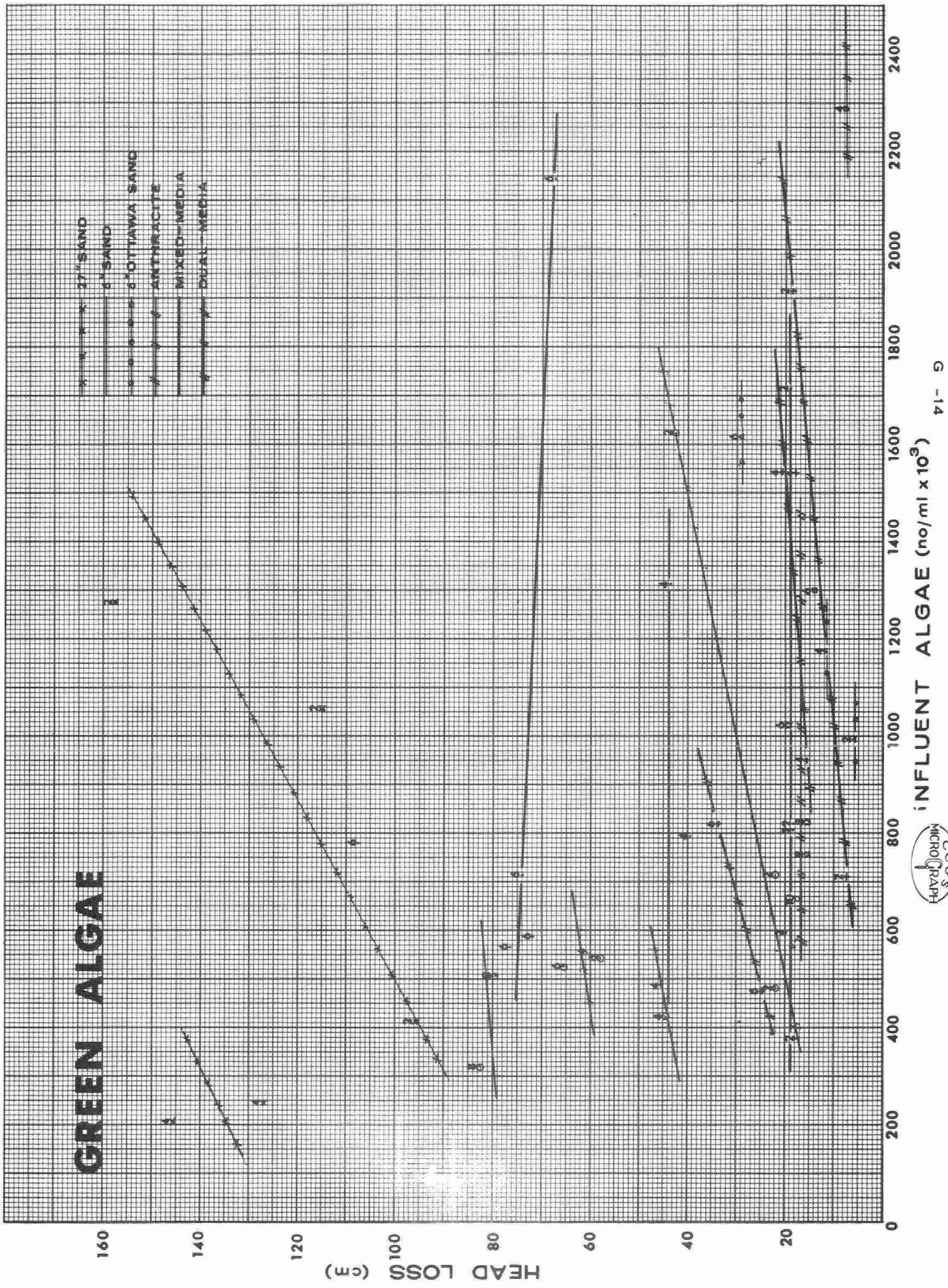
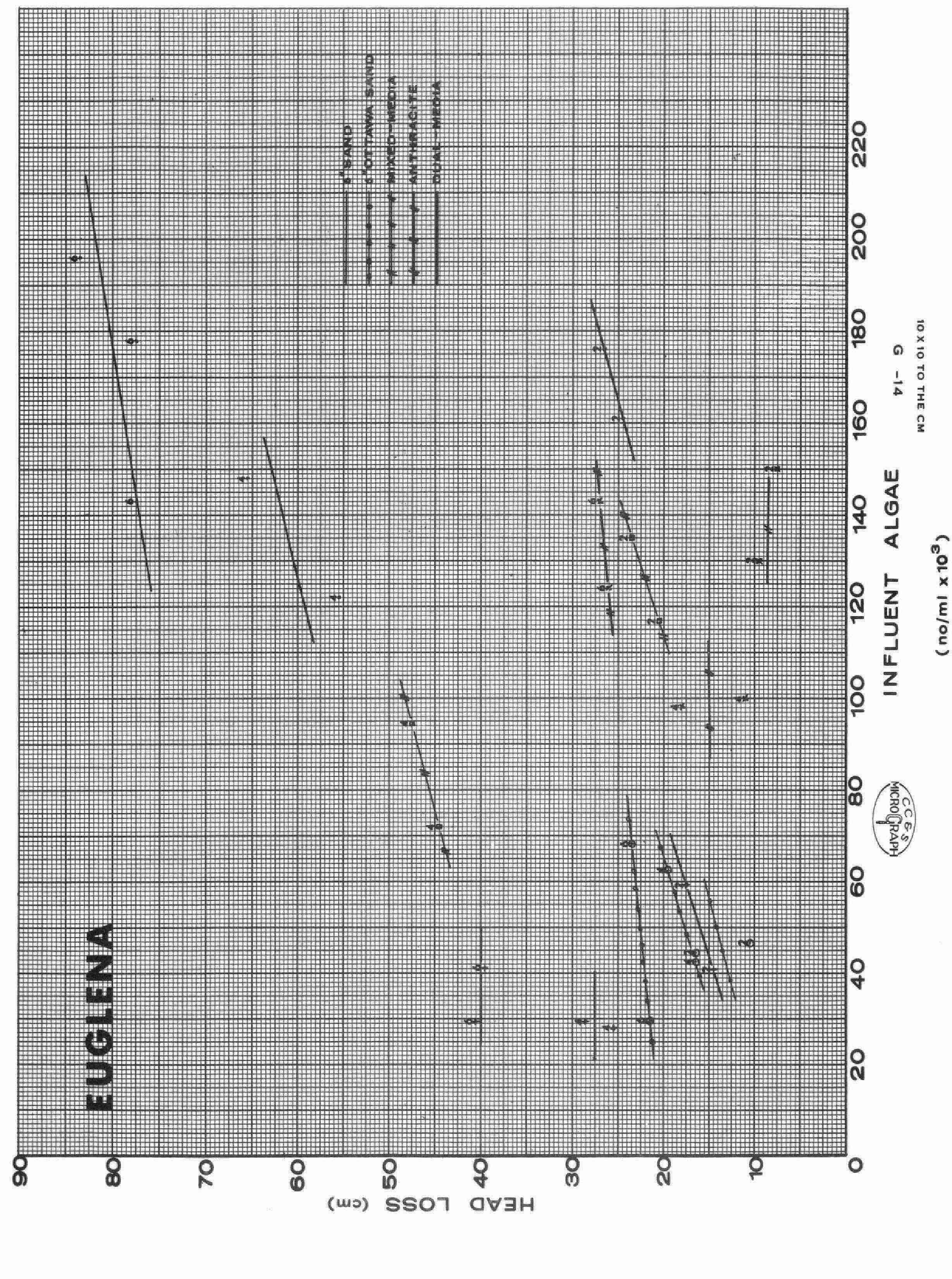


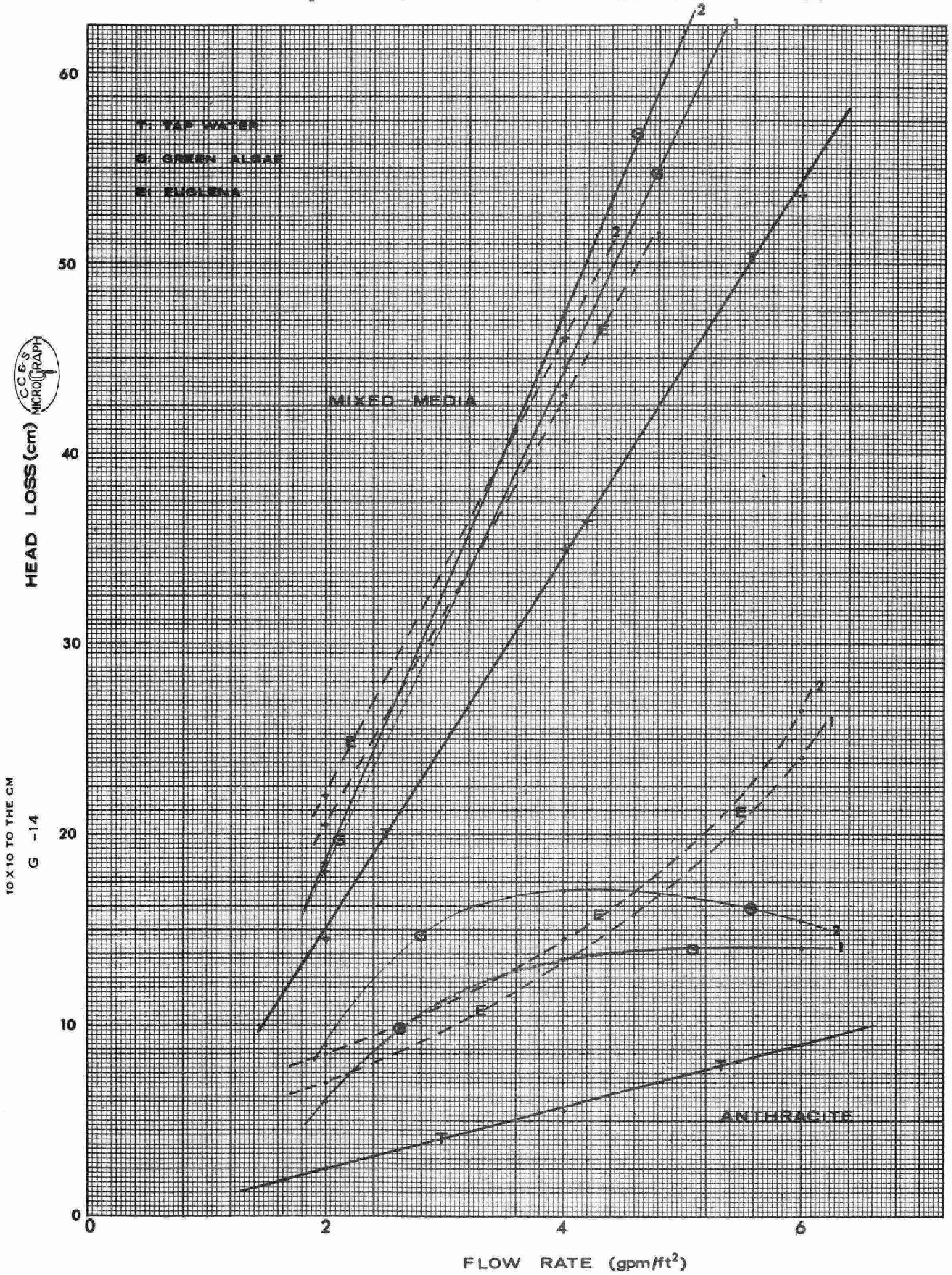
Figure 15: Head Loss vs Influent Algae Concentration 35 -



with the earlier finding that removals of the *Euglena* by the filters were considerably higher. The green algae had little effect on head loss in the Ottawa sand and dual-media filters. The effect of the green algae and *Euglena* on head loss was similar for both the mixed-media and anthracite filters.

Although these data can be described qualitatively, it is felt that little confidence could be placed in any mathematical formulation of the relationships between head loss, flow rate and algal concentration.

Figure 16A: Head Loss vs Flow Rate



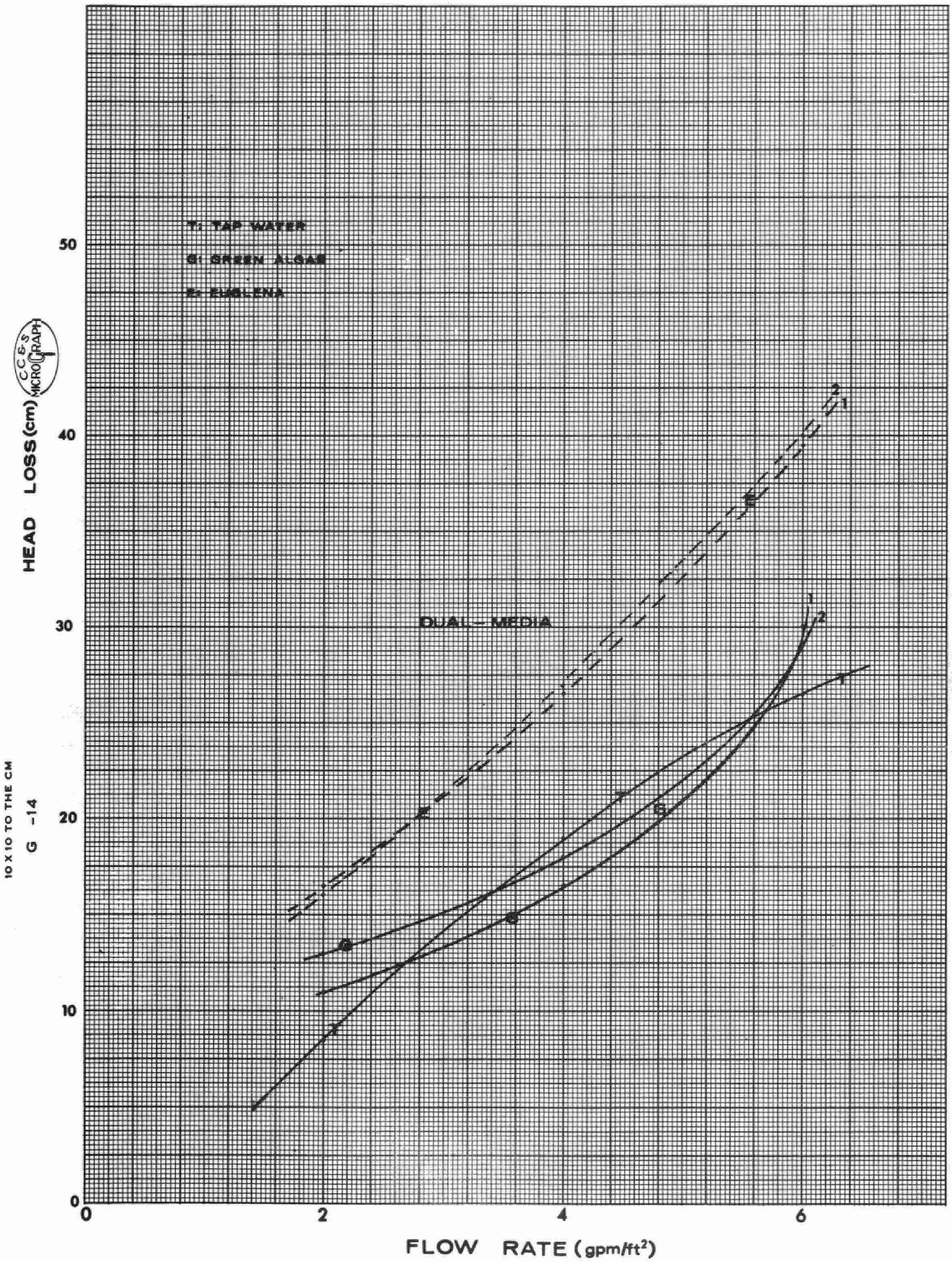
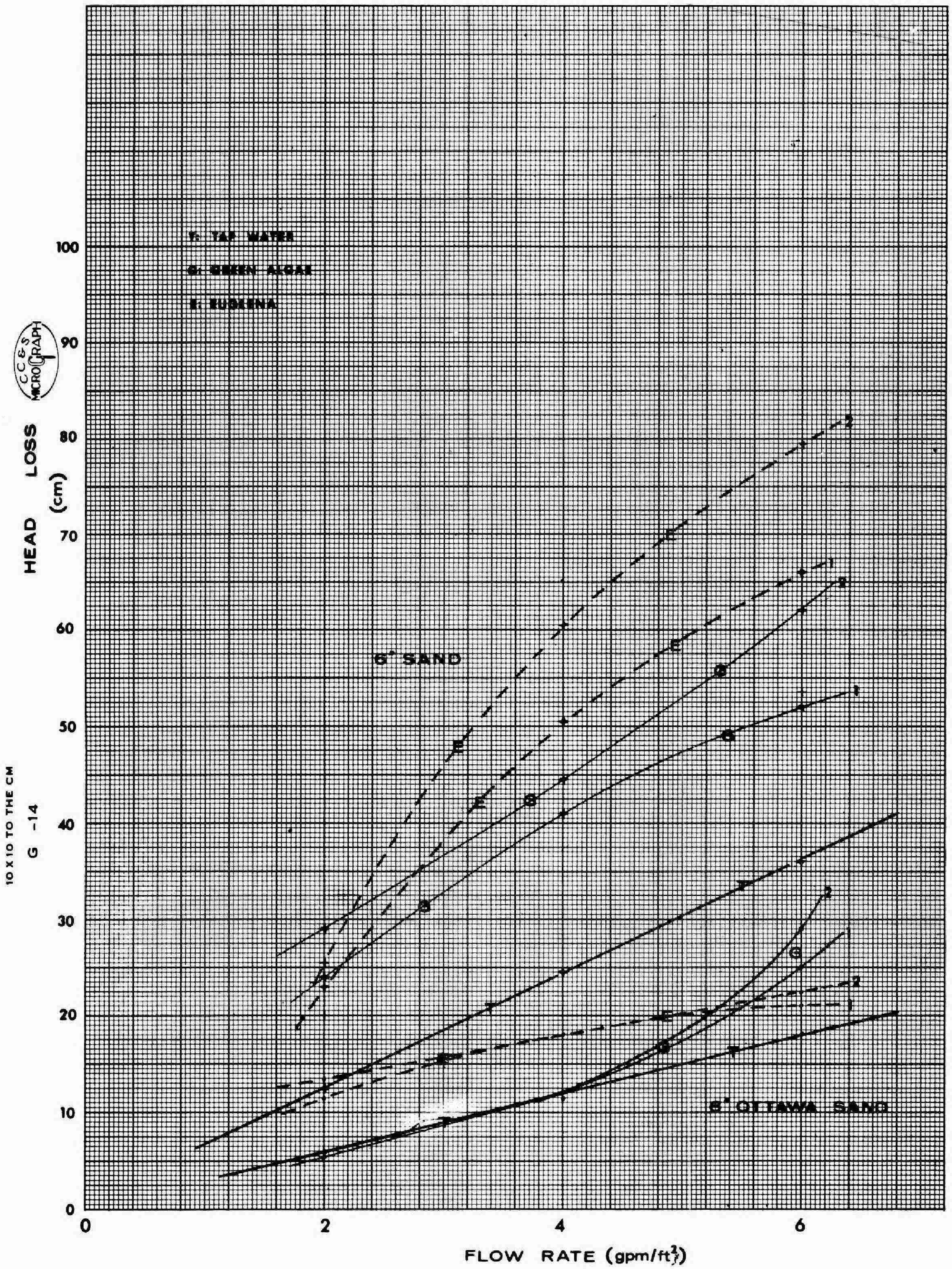

T: TAP WATER
G: GREEN ALGAE
E: EUGLENA
DUAL - MEDIA
HEAD LOSS (cm)
FLOW RATE (gpm/ft²)
0
2
4
6
10
20
30
40
50
T
G
E
1
2
C C & S MICROGRAPHICS
10 X 10 TO THE CM
G -14

Figure 16C: Head Loss vs Flow Rate



4 CONCLUSIONS

1. None of the filter media examined were very effective in removing algae. Only 50% of the *Euglena* were retained by the filters on the average, and 18% of the *Chlorella*, *Scenedesmus* and *Oocistus*.

2. The dual-media and anthracite filters provided the best combination of algae removals with lowest head losses. The mixed-media bed was not quite as efficient with regard to head loss, but algae retention was about the same. Although the 27" sand filter provided high retention of the green algae, head losses were very high compared to those experienced with other media.

3. There was no consistent difference in algae removal with flow rate. In general, higher algal loadings produced higher head losses, but it was not possible to make a quantitative prediction of head loss for a particular flow rate and concentration of algae.

4. The correlation between algae counts and recorded turbidities was poor, indicating that the nepholometric turbidimeter could not be used to estimate algae concentrations in place of counting procedures.

RECOMMENDATION

1. Gravity filters alone should not be considered for removal of algae from raw water supplies.